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14. ABSTRACT
TO GAIN MARITIME DOMINANCE IN THE LITTORALS IN THE 2020 TIMEFRAME, THE US NAVY MUST HAVE CAPABILITIES TO ASSURE ACCESS TO THE LITTORALS AND TO ENABLE SEA BASING AND SEA STRIKE. THESE CAPABILITIES NECESSITATE INNOVATIVE AND RADICAL CONCEPTS FOR SYSTEMS, TACTICS, SUPPORT, AND FORCE STRUCTURES. FOCUSING ON ONLY SYSTEM-OF SYSTEMS (SOS) CONCEPTS, WE CONSIDER A SYSTEM OF ONLY MANNED PLATFORMS, A SYSTEM OF PRIMARILY UNMANNED PLATFORMS, AND A BALANCED HYBRID SYSTEM OF MANNED AND UNMANNED PLATFORMS. BASED ON A COST, RISK-TO-PERSONNEL, PERFORMANCE, AND SENSITIVITY ANALYSIS, USING A SHALLOW WATER ACOUSTICS TOOLSET (EXCEL/SWAT), THE AUTONOMOUS LITTORAL WARFARE SYSTEMS EVALUATOR DISCRETE EVENT SIMULATION (ALWSE), AND A FORCE/THEATER EXTEND™ MODEL, WE SELECT A BALANCED HYBRID SYSTEM OF MANNED AND UNMANNED PLATFORMS THAT USES DISTRIBUTED COMMUNICATIONS NETWORK ARCHITECTURE AND A DECENTRALIZED COMMAND AND CONTROL STRUCTURE. OUR WORK DEMONSTRATES THAT UNMANNED PLATFORMS, WHILE COST EFFECTIVE AND CAPABLE OF REDUCING RISK TO PERSONNEL, COMPLEMENT BUT CANNOT REPLACE MANNED PLATFORMS. MANNED PLATFORMS WILL STILL BE REQUIRED FOR COMMAND AND CONTROL, CRUCIAL OPERATIONAL DECISION MAKING, AND LOGISTICS SUPPORT TO UNMANNED VEHICLES. FINALLY, WE SUGGEST FURTHER RESEARCH TO PROVIDE ADDITIONAL INSIGHT INTO THE SOLUTION TO THE PROBLEM OF MARITIME DOMINANCE IN THE LITTORALS.

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CONCEPTUAL SYSTEM OF SYSTEMS ENABLING MARITIME DOMINANCE IN THE LITTORALS

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ABSTRACT

To gain maritime dominance in the littorals in the 2020 timeframe, the US Navy must have capabilities to assure access to the littorals and to enable Sea Basing and Sea Strike. These capabilities necessitate innovative and radical concepts for systems, tactics, support, and force structures. Focusing on only system-of systems (SoS) concepts, we consider a system of only manned platforms, a system of primarily unmanned platforms, and a balanced hybrid system of manned and unmanned platforms. Based on a cost, risk-to-personnel, performance, and sensitivity analysis, using a Shallow Water Acoustics Toolset (Excel/SWAT), the Autonomous Littoral Warfare Systems Evaluator Discrete Event Simulation (ALWSE), and a Force/Theater Extend™ Model, we select a balanced hybrid system of manned and unmanned platforms that uses distributed communications network architecture and a decentralized command and control structure. Our work demonstrates that unmanned platforms, while cost effective and capable of reducing risk to personnel, complement but cannot replace manned platforms. Manned platforms will still be required for command and control, crucial operational decision making, and logistics support to unmanned vehicles. Finally, we suggest further research to provide additional insight into the solution to the problem of maritime dominance in the littorals.

INTRODUCTION

With the Soviet decline as a combat competitor to the United States, combat has shifted from blue water to littoral regions. Unlike in blue-water combat operations, the responsive

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reaction time of the warfighter in littoral combat operations is reduced, because he is now closer to the threat, and sensor response and performance are degraded by the rapidly changing littoral environment. The shift towards littoral combat operations thus requires that a system of systems (SoS) be capable of overcoming the challenges of short reaction times and littoral environments. By a system of systems it is meant an aggregation of independent systems interlinked to execute a military mission.

In 2001 and 2002 the Naval Warfare Development Command investigated and demonstrated the utility of flotillas of small, fast craft in littoral waters in facilitating forcible entry to an adversary's territory. The Total Ship Systems Engineering SEA LANCE project at the Naval Postgraduate School (NPS) produced a concept of such a small craft, SEA LANCE (SEA LANCE 2002). Such small vessels operating in an adversary's littoral waters would presumably be very vulnerable. Resolution of this issue precipitated the first Systems Engineering & Analysis (SEA) interdisciplinary project, dubbed "CROSSBOW". In this CROSSBOW study the SEA2 students (SEA cohort 2) developed a concept of operations at the total force level for a system of systems which would permit the deployment of weapon and sensor grids in an adversary's littorals, using the small, fast SEA LANCE ships, but with a degree of air support that enhanced the likelihood of success. The CROSSBOW study indicated a need for unmanned combat air vehicles (UCAV) operating from a small, fast ship platform, augmented by unmanned air vehicles (UAV) for surveillance and similar missions. The CROSSBOW force consisted of SEA ARCHER, small, fast ships (13,000 LT, 60 kts) with a UCAV/UAV "air wing", the SEA ARROW UCAV, the SEA QUIVER logistic support ships and other elements (SEA 2001). The CROSSBOW effort was widely recognized as a useful educational tool as well as a vehicle for fostering innovative thinking beyond the NPS campus. As a result, SEA cohort 3, in response to a tasking from the Chief of Naval Operations staff undertook an examination of Expeditionary Warfare in the 2015 timeframe. It investigated the placement of a Marine Expeditionary Brigade as far as 200 nautical miles (nm) inland, to be inserted in accordance with Ship To Objective Maneuver doctrine and to be supported from a Sea Base located as far as 200 nm offshore, by conducing a detailed comparative analysis of the current, planned (current and programs of record) and conceptual expeditionary warfare systems of systems. The conceptual architecture was defined by adding the systems designed by the supporting teams to the planned Navy/Marines Corps expeditionary warfare capabilities SEA 2002). The task of the next interdisciplinary study addressed the area of force protection, focusing on Force Protection of the Sea Base and a design of the "mission modular" Littoral Combat Ship (LCS) optimized for the force protection role. It examined the relative effectiveness of distributed weapons and sensors in a networked environment in protecting a specific Sea Base. The SEA4 work concluded that the force protection mission would benefit greatly from an increased use of unmanned vehicles of all kinds.

The results of the preceding studies motivated an exploration of the role of unmanned vehicles -- Unmanned Air Vehicles (UAV), Surface Vehicles (USV) and Underwater Vehicles (USV) -- in enabling key SEA POWER 21 concepts of SEA BASING and SEA STRIKE (Clark 2002) for maritime dominance in the littorals in the 2020 timeframe. SEA BASING is defined as the massing of supplies and equipment on a seaborne platform hosting a family of systems that maximize projection of Naval Power and SEA STRIKE as the projection of power from sea-based assets to all littoral targets. Tasked to undertake such exploration (Calvano 2003), we define and scope the *littoral maritime dominance problem* as follows.

> Define and select a cost-effective system of systems (SoS) architecture and its concept of operations that would enable SEA BASING and SEA STRIKE for maritime dominance in the littorals in the 2020 timeframe. The SoS would consist of sea-based, land-based, an airborne sensor and weapon systems that are (i) both manned and unmanned, (ii) in existence, in development, and future concepts, and (iii) networked via communications links and space systems to achieve success of the following littoral missions in a littoral area of 200 nautical miles inland by 200 nautical miles offshore, with the minimum risk to personnel: (1) Establishment of the Recognized Maritime Picture (RMP); (2) Identification and, if necessary, reduction of hostile threats to within capability of the sea base; and (3) enabling projection of offensive capabilities from the sea.

Subscribing to the usual systems engineering process and starting with the problem immediately defined above, we generate SoS alternatives, model, analyze and score the SoS alternatives, and select and implement the most cost effective and best performing SoS. This 'soup to nuts' comprehensiveness distinguishes this effort from the previous studies. Like the previous studies, this is a coordinated effort from multiple disciplines from the NPS Integrated Project, incorporating both individual and team research efforts in areas of physics, information technology, and operational analysis with support from industry and agencies in the Departmen of Defense. Teams from the TEMASEK Defense Systems Institute (TDSI), Fleet Numerical Meteorology Operation Center, NPS Unmanned Aerial Vehicle (UAV) Working Group, Naval Sea Systems Command (NAVSEA), and Naval Surface Warfare Center contribute to the areas of unmanned vehicle reliability and conceptual operations in a littoral operating environment for joint operations. Raytheon, Boeing, Northrop Grumman, and Lockheed Martin also provide relevant information.

We consider three SoS alternative categories: a system of only manned platforms, a system of primarily unmanned platforms, and a balanced hybrid system of manned and unmanned platforms. As key integral parts of the systems engineering process, a cost analysis and a simulative analysis, supported by EXTEND™ (Imagine That 2002), ALWSE-MC (NAVSEA 2003), SWAT, and Excel, lead to the following *primary conclusions* of the study:

> Unmanned vehicles complement but cannot replace manned platforms. The recommended system of systems enabling SEA BASING and SEA STRIKE in 200 nm by 200 nm littoral operation area in 2020 timeframe consists of unmanned/manned vehicle ratio of approximately 1.5 to 1; utilizes distributed communications with 100nm physical platform distribution; employs decentralized command & control structure; and is cost effective relative to other alternatives; and minimizes risk to personnel.

A system of only unmanned platforms thus does not provide a silver-bullet solution to the problem of maritime dominance in the littorals; unmanned platforms thus complement but cannot replace manned systems. Manned platforms are still required to implement command and control and make crucial operational decisions. Unmanned vehicles in the 2020 timeframe by

themselves will not have the ability to adapt to dynamic threat environments. Manned platforms will therefore continue to provide essential command and control element in military force structures. Furthermore, limited in endurance and thereby requiring manned system support, unmanned vehicles cannot completely keep personnel out of harm's way, yet they can greatly reduce the level of risk to which personnel are exposed.

In the remainder of this paper we first describe the different UV types and, in particular, the unmanned systems delivery vehicle (USDV) developed by the TDSI team during this work. We next define three SoS force compositions, describe the SoS architecture attributes, and define SoS architectures. We then postulate the events that lead to the 2020 South China Sea scenario and define three associated tactical scenarios and related threats. We next describe the simulative study along with the simulation tools and algorithms used; this simulative effort provides quantitative measures employed in ranking the different SoS architectures and selecting the cost effective SoS architecture. We continue with a sensitive analysis used to validate the ranking and selection results. Finally, we summarize the findings of this work and conclude with recommendations for further research.

SoS PLATFORM CATEGORIES

Functional analysis leads to a functional architecture, which, embedded in platforms, leads to SoS force compositions. Since the scope of this paper is to present the analysis and simulation that enable selection of an SoS, we only briefly enumerate the SoS top-level functions here. A detailed description of the SoS functions can be found in (SEA5 2004). The functional analysis involves identification and decomposition of the functions to be performed in support of the missions identified in the problem statement above, using Boyd's OODA loop (Observe, Orient, Decide, Act) as a framework (Boyd 1987). The resulting top-level functions are: Surveillance, Threat Analysis and Evaluation, Battle Management, and Engagement.

Unmanned Vehicle (UV) Types

The UV considered in this work are classified according to size – small, medium, and large -- and to the functions of surveillance, strike, and multi-mission. Figure 1 displays some unmanned aerial vehicles (UAV) categorized by size (small, medium, and large). Unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV) are classified solely by the function they perform. With these classifications, the SoS force decompositions will contain five UAV types two USV, and three UUV. Table 1 shows the different UAV types with their respective parameters.

Figure 1. Examples of Small, Medium, and Large Unmanned Aerial Vehicles

Table 1. Unmanned Vehicle Parameters

CLASS	PAYLOAD (lb)	ENDURANCE(hr)	ALT (ft)	EMPLOYMENT	EXAMPLE
1 - Small	< 75	≥ 2.5	> 500	Pneumatic	Silver Fox
2 - Medium	≤ 75 < 1000	≥ 10	> 5000	Pneumatic, Short	Predator B
3 - Large	≥ 1000	> 30	> 10000	Catapult or runway	Global Hawk

The surveillance UAV perform only surveillance and provide information for the development of the Recognized Maritime Picture (RMP). The strike UAV perform only air-to-surface roles, with limited surveillance to allow for weapon targeting. As air-to-air engagement is too complicated, a UAV capable of intercepting and destroying air platforms would not be available by 2020. The multi-mission UAV can also perform surveillance, but not as well as if they are to perform only single missions.

Furthermore, the medium UAV are assumed to be carrier capable. Using the area of the wingspan, the length of the UAV and current manned aircraft, and the dimensions of folded wingspans and fuselages, a simple calculation shows that the deck space of a current carrier can accommodate seventy medium surveillance UAV.

Unmanned Systems Delivery Vehicle (USDV)

We also consider an unmanned vehicle future concept, the unmanned systems delivery vehicle (USDV) developed by the TDSI team during this work, to be included in an SoS force composition. Figure 2 shows the overall configuration of the USDV with its payload packages. The right picture illustrates the deployment of upper deck hatch and the lowering of the lower deck ramp. The USDV would benefit US Navy in many ways (Neo 2004), but in this paper we discuss its role in the littoral warfare. With its already-developed unmanned systems package inserted into the potential battle space, the USDV would take on the initial threat to surface combatants and crews, and thereby, extend the stand-off distance for the host platform and provide an early picture of the littoral battlespace well in advance of the battle group arrival into the area of operation.

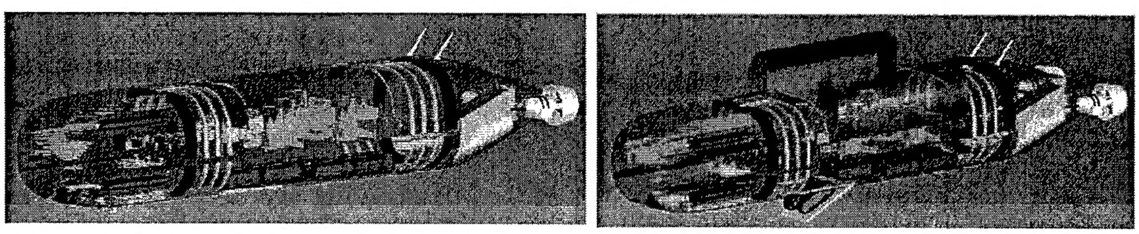


Figure 2. Overall Configuration of the USDV with its Payload Packages (Neo 2004)

SoS ARCHITECTURES

In this work an SoS architecture consists of four variables: Force composition (FC) (or physical platforms), communications network architecture (CNA), and command and control (C2) structure, and platform physical distribution (PPD). Though these variables can form a

large set of values, for computational efficiency, only three values of FC, CAN, and PPD and two values of C2 are chosen. The three values of the communications network architectures (CNA) correspond to enclave, hybrid, and distributed. (Figure 3). The two values of C2 structures correspond to centralized and decentralized structure (Figure 4). These discrete values are chosen to reflect practical SoS employment within the established operating environment. The variables will be discussed in detail later.

Force Compositions

Three force compositions are developed through an *iterative* process. The first force composition consists of only manned systems. The second is a balanced mix of manned and unmanned systems. The third consists of primarily unmanned systems. The first force composition contains 2003-timeframe systems, manned military platforms used today, while the second includes both current systems and some programs of record (POR). The third force composition contains manned systems, POR, and future systems.

The systems to be included in an SoS architecture are assumed to be available and reliable for operation in the 2020 timeframe, such as carrier capable unmanned aerial vehicles and antisubmarine warfare (ASW) capable unmanned underwater vehicles. The multi-mission UUV would presumably take over the ASW role of manned submarines. The carrier capable UAV would replace the manned vehicles scheduled to be decommissioned prior to 2020. Being smaller than their manned counterparts, more unmanned vehicles would be carried on the carrier. Table 2 shows the various elements in three force compositions.

Force Composition One – Manned Only

Force Composition One contains only manned systems, reflecting those in the current carrier battle group (CVBG) and mine warfare assets and Air Force units for operations support. A balanced hybrid of manned and unmanned systems, Force Composition Two includes surveillance unmanned vehicles and programs of record such as the Littoral Combat Ship (LCS). Primarily unmanned, Force Composition Three includes multiple unmanned systems in surveillance, strike, and multi-mission roles as well as future concepts not yet in development.

The aircraft carrier (CVN), E-3 AWACS, and SH-60 are common to all three force compositions. The E-3 AWACS provides air control to manned and unmanned vehicles. The SH-60 undertakes anti-submarine warfare and search and rescue (SAR) during carrier flight operations involving manned aircraft. Force Composition One has ten SH-60Bs, while the other force compositions have only six, due to the eventual phase-out of two frigates (FFG) by 2020.

The Cruiser (CG), Destroyer (DDG), E2-C Hawkeye, E-8 JSTARS, attack submarines (SSN), and F/A-18 Hornets are common to both Force Compositions One and Two. The Cruiser (CG) and Destroyer (DDG) perform surface and air surveillance, and threat analysis and evaluation. The E2-C Hawkeye performs air and surface surveillance as well as battle management. The Air-Force E-8 JSTARS provides ground surveillance and battle management. The attack submarines establish undersea pictures and engage enemy undersea assets. Finally, the F/A-18 Hornets are used for air-to-air and air-to-ground engagements.

Finally, the Land Helicopter Assault ship (LHA), mine warfare ships (MCM and MHC), E/A-6B Prowlers, S-3 Vikings, and F-14 Tomcats complete Force Composition One. The Land LHA carries the MH-53 Sea Stallion helicopters. The MCM and MHC provide surveillance for

mine countermeasures, while the E/A-6B Prowlers, S-3 Vikings and F-14 Tomcats some surveillance and engagement functions. These platforms will be replaced by other aircraft and unmanned vehicles employed in Force Compositions Two and Three.

Force Composition Two – Balanced Hybrid

A replacement of some elements in Force Composition One with manned and unmanned systems creates Force Composition Two. In this hybrid composition of manned and unmanned vehicles, the Littoral Combat Ship (LCS), fitted anti-submarine warfare, anti-surface warfare, and mine warfare modules, replaces the LHA's MH-53 and the Frigates and Mine Hunter/Mine Countermeasure ships. Each anti-submarine warfare LCS has two ASW UUV; each anti-surface warfare LCS two surveillance USV; and each Mine warfare LCS two mine UUV. Force Composition Two also incorporates the Joint Strike Fighter (JSF) and the Multi-Mission Aircraft (MMA), which replaces the P-3. The air wing on the carrier consists of SH-60Bs, E2-Cs, F/A-18s, JSF and medium surveillance UAV. The F/A-18 Super Hornet takes on the S-3 tanker role and the EA-6B electronic warfare role. The F/A-18 Super Hornet and the surveillance UAV assist with RMP development, and the F-22 and F/A- 16 contribute to the joint engagement mission.

Force Composition Three – Primarily Unmanned

Force Composition Three, the primarily unmanned composition, incorporates a large number of unmanned vehicles and future systems such as DDX, CGX and LCS. Except for the JSF, SH-60B and the E-3 AWACS, which are needed for air-to-air combat and battle management, the manned aircraft in the other force compositions are replaced by the multi-mission and strike unmanned vehicles. The multi-mission USV would perform surface surveillance and interdict small patrol boats. Also, the USDV is used to carry short-range UV from blue (deep) water into the littoral region. Eight large surveillance UAV replace the E-2C Hawkeye. The large surveillance UAV perform air and surface surveillance.

Table 3 lists only the SoS platforms that have sensors; Table 4 the type and number of weapons onboard each weapon-carrying SoS platform; and Table 6 the maximum number of personnel manning a SoS platform.

Communications Network Architectures

Figure 3 shows the three different CNA considered in this work – enclave, hybrid, and distributed. The enclave architecture provides the lowest level of communication connectivity (represented by dashed lines) among platforms. Platforms at lower levels must thus utilize platforms at higher levels to carry out communications. Consequently, a large number of communications nodes (hops) is required to connect any two platforms. The hybrid CNA configuration expands connectivity among platforms by adding to the enclave connectivity new lines of communication between many platforms at peer levels. This additional connectivity thus, on average, reduces the number of hops required to connect platforms. The hybrid architecture most closely resembles the current Navy/Joint communications architecture employed in the tactical environment. Finally, in the distributed CNA nearly all platforms are capable of direct communications. As a result, the number of hops required to connect platforms

is significantly reduced. The distributed CNA thus provides the highest level of connectivity among platforms.

Command and Control Structures (C2)

A C2 structure determines the level of command, establishing which platforms perform C2 functions (represented as C2 nodes). Orders initiate and reports terminate at these C2 nodes; hence, the C2 nodes determine the flow of communications throughout an SoS architecture. In this work, we consider two C2 structures – centralized and decentralized. The centralized structure places the C2 node(s) at the highest level; it thus increases the effective communications path length between reporting, C2, and ordinate platforms. The decentralized structure places the C2 nodes at the mid level of the architecture, thus reducing the effective communications path length between platforms. Figure 4 depicts the two C2 structures.

Table 2. SoS Force Compositions

Platform	SoS 1 (Manned)	SoS 2 (Balanced Manned/UVHybrid)	SoS 3 (Primarily Unmaned)
CVN	1	1	1
CG	2	2	0
CGX	0	0	2
DDG	4	2	0
DDX	0	0	2
LCS	0	6	6
FFG	2	0	0
MHC	1	0	0
MCM	1	0	0
LHA	1	0	0
SSN	2	2	0
E-2C	4	4	0
E-8	1	1	0
E-3	1	1	1
P-3	2	0	0
MMA	0	2	0
SH-60	10	7	6
MH-53	6	0	0
F/A-18	36	24	0
F-14	14	0	0
E/A-6B	5	0	0
B-2	1	0	0
B-52	2	0	0
F-117	2	0	0
JSF	0	18	14
F-16	0	6	0
F-22	0	6	0
S-3	8	0	0
SSGN	0	2	0
USV-1	0	4	0
USV-2	0	0	4
UAV-1	0	2	8
UAV-2	0	70	30
UAV-3	0	20	20
UAV-4	0	0	30
UAV-5	0	0	50
MIW UUV	0	4	4
ASW UUV	0	4	10

Table 3. SoS Architecture Sensors

	SoS Sensor Types				
SoSPlatformType	Surface Sensor	Air Sensor	Subsurf Sensor	Mine Sensor	Land Sensor
CG	EF-Band	EF-Band	Surf Sonar		
CGX	K-Band	K-Band	Surf Sonar		
DDG	EF-Band	EF-Band	Surf Sonar		
DDX	X-Band	X-Band	Surf Sonar		
LCS	AN/SPS 67		Surf Sonar	Surf	
FFG	AN/SPS 55	AN/SPS 49	Surf Sonar		
MHC				Surf	
MCM				Surf	
SSN			Sub Sonar		
E-2C	Air Borne B-Band	B-Band			
E-3	Air Borne B-Band				
P-3			Air Sonar (P3)		FolPen
MMA			Air Sonar (P3)		FolPen
SH-60	EF + IR				
MH-53				Helo	
S-3	IR		Air Sonar (P3)		FolPen
SSGN			Sub Sonar		
USV-1	AN/SPS 55D + 67	B-Band (Degraded)			
USV-2	AN/SPS 55D + 67 + IR				
UAV-1	B-Band (Degraded)	B-Band (Degraded)			
UAV-2					FolPen
UAV-3	IR				
UAV-5					FolPen
MIW UUV				UUV	
ASW UUV			UUV Sonar		

Platform Physical Distributions (PPD)

The spatial distribution of the platforms in the littoral area is called the physical platform distribution. The PPD diameter is the distance between the two farthest platforms in the distribution or network. It is a measure of the spatial extent of the distribution of sensor and weapon platforms as well as ranges between communications nodes. In this work we consider three PPDs – small, medium, and wide. The distribution diameters of the small, medium, and wide PPDs are, respectively, 50 nm, 100 nm, and 150 nm. Figure 5 depicts the three PPD schematics.

SoS Architecture Alternatives

An SoS architecture is thus a quadruplet, A = (FC, CAN, C2, PPD), where FC = 1 for Force Composition One, 2 Force Composition Two, and 3 Force Composition Three, CNA = 1 for enclave, 2 hybrid, and 3 distributed , C2 = 1 for centralized and 2 decentralized, and PPD = 1 for small, 2 medium, and 3 large. There are thus fifty four distinct SoS architectures. For example, (2, 1, 2, 2) means an architecture that uses the hybrid force composition, the enclave communication architecture, the distributed C2 structure, and the medium platform physical distribution.

The simulative study evaluates the performance of these fifty-four architectures against the different tactical scenarios, which are described next

Table 4. SoS Architecture Weapons

SoS Weapon Types						SoSWeapons (#)				
SoS Platform	Surface	Air	Sub Surf	Mine	Land	Surface	Air	Sub Surf	Mine	Land
CVN		Sea Sparrow					32			
CG	Harpoon	SM-RAM	Torpedo		Tomahawk	8	63	6		64
CGX	Harpoon	SM-RAM	Torpedo		Tomahawk	8	63	6		64
DDG	Harpoon	SM-RAM	Torpedo		Tomahawk	8	45	6		45
DDX	Harpoon	SM-RAM	Torpedo		Tomahawk	8	45	6		45
LCS	57mm Gun	RAM	Torpedo	MH-63 Sled		8	11	6	1	
FFG	Harpoon	RAM	Torpedo			2	11	6		
MHC				MH-63 Sled					2	
MCM				MH-63 Sled					2	
LHA		RAM					42			
SSN	Torpedo		Torpedo		Tomahawk	1		1		12
P-3	Harpoon		Torpedo			1		4		
MMA	Harpoon		Torpedo			1		4		
SH-60	Penguin		Torpedo			1		2		
MH-53				MH-53 Sled					1	
F/A-18	Harpoon	AIM-9X			JSOW	2	2			2
F-14	Harpoon	AIM-9X			JSOW	2	2			2
E/A-6B					HARM					4
B-2					JDAM					8
B-52					JDAM					6
F-117					JDAM					1
JSF	Harpoon	AIM-9X			JSOW	2	2			2
F-16	Harpoon	AIM-9X			JSOW	2	2			2
F-22	Harpoon	AIM-9X			JSOW	2	2			2
S-3	Harpoon		Torpedo			1		2		
SSGN	Torpedo		Torpedo		Tomahawk	1		1		154
USV-2	Hellfire			USV Sled		2			1	
UAV-4	Harpoon				JSOW	1				1
UAV-5	Hellfire				Hellfire	1				1
ASW UUV	Torpedo		Torpedo			2		2		

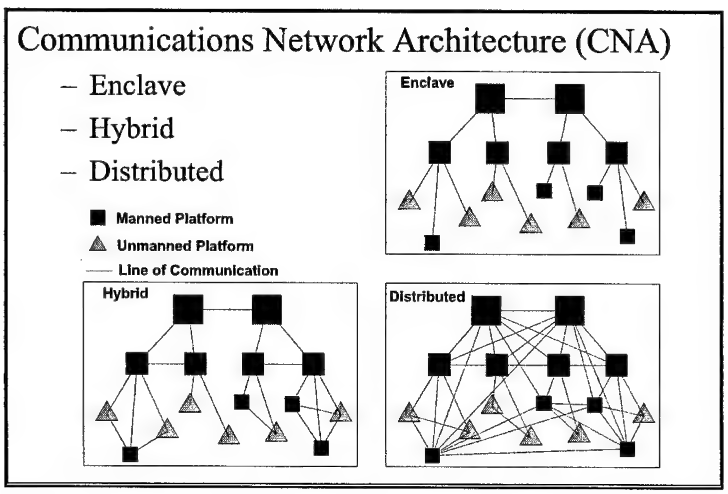


Figure 3. Communications Network Architecture

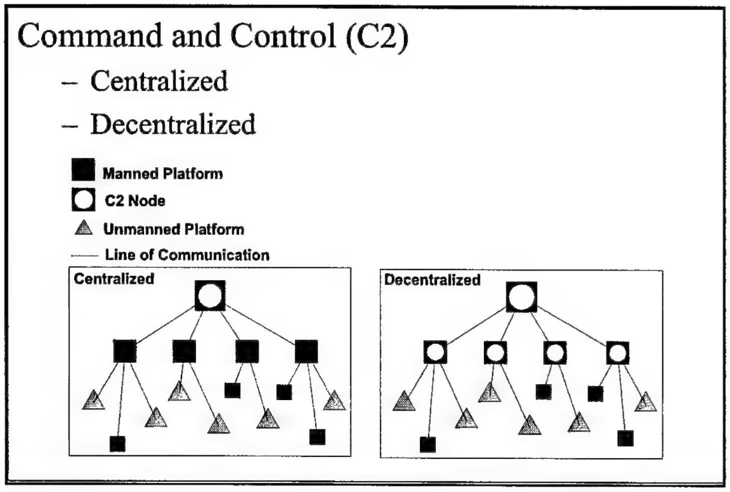


Figure 4. Command and Control Structure

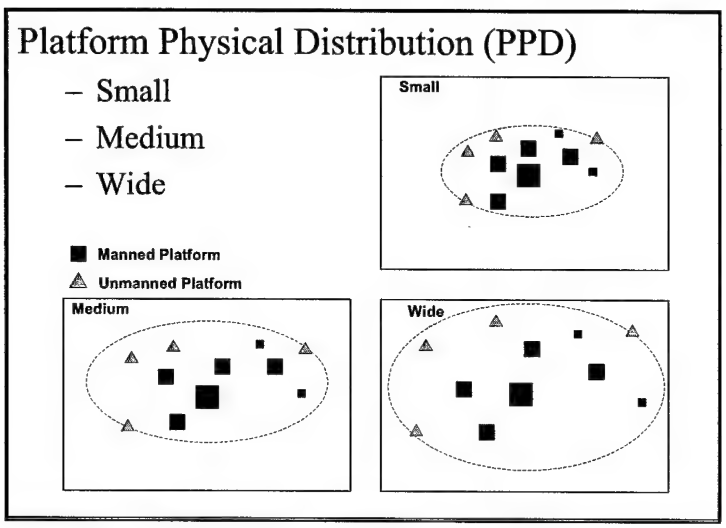


Figure 5. Physical Platform Distribution

Table 5. SoS Architecture Personnel

SoS Personnel			
SoSPlatformType	Personnel (#)	SoSPlatformType	Personnel (#)
CVN	5680	F-14	2
CG	364	E/A-6B	4
CGX	120	B-2	2
DDG	323	B-52	5
DDX	98	F-117	1
LCS	50	JSF	1
FFG	220	F-16	1
MHC	51	F-22	1
MCM	84	S-3	2
LHA	964	SSGN	155
SSN	129	USV-1	0
E-2C	5	USV-2	0
E-8	21	UAV-1	0
E-3	15	UAV-2	0
P-3	11	UAV-3	0
MMA	11	UAV-4	0
SH-60	3	UAV-5	0
MH-53	6	MIW UUV	0
F/A-18	1	ASW UUV	0

THREATS AND SCENARIOS

For the purpose of SoS architecture evaluation we assume that the LMD SoS will be deployed against the People's Republic of China (PRC), a US near-peer competitor. *The selection of the PRC as the opposition forces in the South China Sea Region in no way represents the view of the Naval Postgraduate School, the Navy, and the United States.*

US force compositions in an SoS architecture are discussed above, which are based on the Naval Expeditionary Strike Group (NESG) model. Operating areas are scoped within a bounded area of responsibility 200 nautical miles (nm) along the littoral coast, reaching up to 200 nm into land and out to sea from the coast. Task Force Commanders are expected to have sufficient forces and logistics necessary to initiate mission tasking in a joint military operation. Interoperability issues (e.g., intercommunications capability, sensor interface, and logistic lines of communication,) will have been resolved prior to SoS deployment

People's Republic of China (PRC) Forces

As open source information about PRC capabilities in the 2020 timeframe is extremely limited (Annual Report 2003, Stokes 1999, FAS), we assume the future PRC capabilities enunciated in the NPS integrated Joint Campaign Analysis (JCA) study of the South China Sea Scenario. Table 5 lists the probabilities of kill of the threats against the SoS platforms. These values reflect threat weapon capabilities (Globalsecurity.org & Sinodefence.com) and the physical SoS platform characteristics only, and not the SoS defensive capabilities.

Table 5. PRC Weapons Kill Probability, P(K)

	Enemy P(K)										
SoSPlatform	DDG	FFG	PGM	Fighter	Bomber	Missile	Diesel Sub	Nuc Sub	Mini Sub	Mine	Launcher
CVN	0.4	0.4	0.4	0.75	0.8	0.4	0.3	0.3	0.2	0.3	0.4
CG	0.5	0.5	0.5	0.75	0.8	0.5	0.4	0.4	0.3	0.5	0.5
CGX	0.5	0.5	0.5	0.75	0.8	0.5	0.4	0.4	0.3	0.5	0.5
DDG	0.6	0.6	0.6	0.75	0.8	0.6	0.5	0.5	0.4	0.6	0.6
DDX	0.6	0.6	0.6	0.75	0.8	0.6	0.5	0.5	0.4	0.6	0.6
LCS	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
FFG	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
MHC	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
MCM	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
LHA	0.7	0.7	0.7	0.75	0.8	0.5	0.4	0.4	0.3	0.5	0.5
SSN	0.5	0.5					0.3	0.3	0.2	0.7	
E-2C	0.7	0.6		0.75		0.7					0.7
E-8	0.7	0.6		0.75		0.7					0.7
E-3	0.7	0.6		0.75		0.7					0.7
P-3	0.7	0.6		0.75		0.7					0.7
MMA	0.7	0.6		0.75		0.7					0.7
SH-60	0.7	0.6		0.75		0.65					0.65
MH-53	0.7	0.6		0.75		0.65					0.65
F/A-18	0.6	0.5		0.6		0.4					0.4
F-14	0.6	0.5		0.6		0.4					0.4
E/A-6B	0.6	0.5		0.75		0.5					0.5
B-2	0.7	0.6		0.75		0.7					0.7
B-52	0.7	0.6		0.75		0.7					0.7
F-117	0.6	0.5		0.75		0.4					0.4
JSF	0.6	0.5		0.6		0.4					0.4
F-16	0.6	0.5		0.6		0.4					0.4
F-22	0.6	0.5		0.6		0.4					0.4
S-3	0.7	0.6		0.75		0.65					0.65
SSGN	0.4	0.4					0.4	0.5	0.3	0.7	
USV-1	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
USV-2	0.7	0.7	0.7	0.75	0.8	0.7	0.6	0.6	0.5	0.7	0.7
UAV-1	0.7	0.6		0.75		0.7					0.7
UAV-2	0.7	0.6		0.75		0.7					0.7
UAV-3	0.7	0.6		0.75		0.7					0.7
UAV-4	0.7	0.6		0.75		0.7					0.7
UAV-5	0.7	0.6		0.75		0.7					0.7
MIW UUV	0.5	0.5					0.4	0.5	0.3	0.7	
ASW UUV	0.5	0.5					0.4	0.5	0.3	0.7	

We assume also that the PRC lags five to ten years behind the US in technological advances. Consequently, an SoS would face mostly asymmetrical and conventional threats (SUW, USW, MIW, and AAW). Also, despite the PRC military's current effort to improve in-flight refueling, to develop advanced stealth technologies, and to build nuclear vessel aircraft carriers and submarines, it will not have unmanned vehicles and focused energy weapons in 2020. Furthermore, presumably obligated by other interests, the PRC Army-Air Force (PLAAF) assets will not be available for reinforcement. The PRC assets used in the tactical scenarios thus comprise all available assets in theatre. Finally, no other nations in the region provide forces to reinforce the PRC units.

Events Leading to 2020 Scenarios

In 2010, having been peacefully united with Taiwan, the PRC now focuses it attention to the South China Sea region and its western borders.

In 2015, the PRC Navy reinforces its presence in the Spratly Islands (specially on Mischief and Alison Reef) by installing three paved runways, pier and maintenance facilities, Air Defense Artillery (ADA) batteries, and ballistic missile sites. The Philippines, Vietnam, Indonesia, Malaysia, Australia, Singapore, Japan, and the United States individually condemn the PRC's action and Spratlys development, but fall short on a combined response. Indonesia, Malaysia,

and the Philippines, however, form a defense treaty and protest China's aggressive behavior in the area. The United States and the Philippines have previously established a similar treaty in 2010.

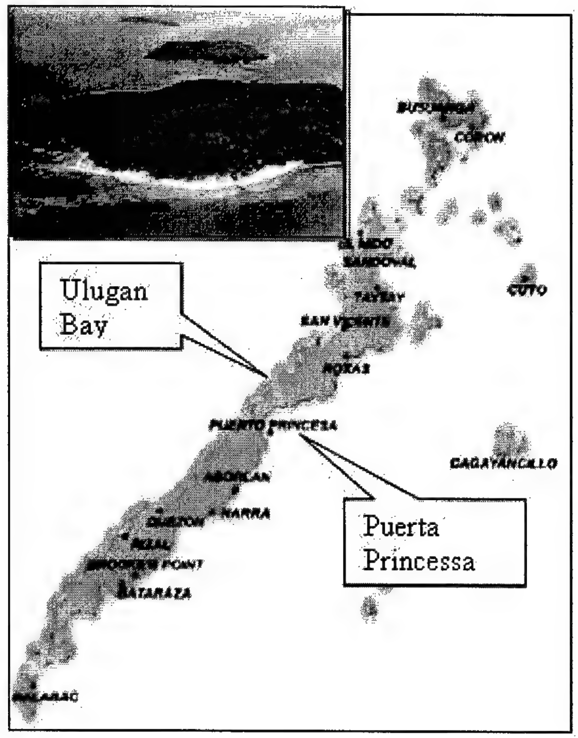


Figure 6. Map of Palawan Island

The year is 2020. To affirm rights to the offshore oil reserves in the South China Sea, the PRC now increases its naval presence in the South China Seas by deploying ships and aircraft from its northern fleets to augment the South China Fleet. Despite repeated protests, PRC naval exercises frequently disregard the territorial seas of the Philippines, Malaysia, and Indonesia. Early in the year 2020, a Philippine jet aircraft, having warned a PRC warship to clear the area, strafes a PRC destroyer that is firing its gun within two miles of Palawan Island's coast (Figure 6). Ten PRC sailors are killed and the destroyer returns fire but fails to hit the aircraft. International tensions begin to rise in response.

Two months have passed since the strafing incident and, claming self-defense and the need to establish a "safety" perimeter around the South China Sea, the PRC invades Kepulauan Natuna (Indonesia) with a division of PRC infantry, supported by air defense regiments, and ten shore-based anti-ship missile batteries. The PRC further threatens to invade Palawan Island (Philippines) if any of the Association of Southeast Asian Nations (ASEAN) nations reacts. PRC forces have not yet begun overtly hostile actions against the Philippines, but several PRC surface combatants are steaming easterly from the Spratlys.

US force dispersion in the region is heavily affected by the change in national policy and the evolution of military technology. With *KITTY HAWK's* decommissioning in 2008, no US conventional carrier is available to station in Japan. Instead, a NESG, composed of one LHD (Yokosuka), two LPD-17 (Sasebo), 2 FFG (Sasebo), two older Aegis CG (TBMD capable), and

three DDG (not TBMD capable), remains forward deployed in Japan along with one MEU-sized Marine force in Okinawa. The Amphibious ships in Japan provide the amphibious lift for the Okinawa Marines. All other U.S. forces, including those in Korea, have been withdrawn to the United States and now form Expeditionary Forces. Currently, one carrier battle group and one naval expeditionary strike group are both underway east of Leyte Gulf and can be redirected to the region. US forces are now also augmented with unmanned vehicles. In response to the growing tension in the region, Commander Pacific (COMPAC) has stood up Commander Joint Task Force (CJTF) Sea Tiger to monitor the situation and construct plans should occupation of Philippine territory become a reality.

Tactical Scenarios

The South China Sea scenario spawns three separate scenarios of gradually increasing level of difficulty with time for US forces. A level of difficulty is characterized by (a) mission tasking, (b) enemy force structure, and (c) level of hostility. Scenario One signifies a benign operating environment, Scenario Two a nominal environment, and Scenario Three a stressing environment. The increasing intensity of the three factors, hence, an increasing level of difficulty, increases linearly from Scenario One to Scenario Three. Figure 7 schematically depicts the levels of difficulty of three scenarios – benign, medium, and stressing.

Scenario One (Benign Scenario)

The PRC government immediately calls for a treaty with the Philippines and Indonesia to establish a New Era of South China Sea Cooperation among perimeter nations and gives them one month to respond. Led by the United States, the ASEAN nations condemn the PRC's action and submit a joint U.N. resolution to establish sanctions against the PRC. The Security Council vetoes the resolution.

The PRC naval forces (Table 6) -- Two Houjain PGMs and five Houxin PGMs -- have begun a thirty-day quarantine of Puerta Princesa port (Palawan) in tandem with the PRC's positioning of a maritime division landing force in the Spratly Islands along with several airborne divisions in the Guangzhou District preparing for invasion. Reports, on occasion, include several sightings of diesel submarines operating along with PRC gunboats, but none as yet confirm PRC mining of harbors. No attempt is made to challenge China's blockade of Palawan.

SoS forces are to locate and identify the PRC forces operating in and around the island of Palawan and the PRC vessels engaging in hostile acts while blockading Puerta Princessa; establishment of a Recognized Maritime Picture (RMP) is a priority for the US forces. The known location of suspected diesel sub operating areas will greatly aid in planning for mission priority and defining strategies. US forces are expected to encounter a benign operating environment.

Scenario Two (Medium Scenario)

A PRC maritime division landing force, augmented by two light infantry and one artillery division, is invading the island of Palawan. The Phillipines officially objects to the occupation and, citing the US-Phillipines Treaty of 2010, it requests international assistance in expelling the

aggressor. The ASEAN Alliance denounces PRC's occupation of Palawan and, backed by US diplomatic pressure, pushes once more for UN sanctions against the PRC requiring reparations on behalf of the Phillipines. The motion fails, vetoed by the Security Council.

PRC reinforcements are now forward staged in the Spratlys through the Paracel Islands (Table 6), which include two infantry, two artillery, and one armored division. The PRC forces have begun immediate fortifications of Puerta Princessa Airport as well as heavy defensive mining along the southern shores and within the harbor. Fifty DF-21 MRBM are being relocated to the Paracel Islands. Twenty TU-16 Badgers (air-to-surface capable) are flying into Puerta Princessa Airport to conduct routine coastal patrols. The 48-kiloton Aircraft Carrier (thirty SU-30 fighters) has taken up routine operations northwest of the Palawan's northern tip while submarine sightings in both the Sulu and Philippine Seas are routine. As of the 33rd day of the blockade, ten Jiangwei FFG, ten Houjain PGM, twenty Houxin PGM are positioning themselves in coves along the Palawan coast while the first of three Sovremny DDG (remaining two vessels spotted via satellite steaming southward just east of the Paracels) is making berth in Puerta Princessa.

US RECCE operations are being upgraded to target evaluation. Deployed forces are to identify both actual and likely PRC troop defensive positions. SAG commanders should forward recommended target selections and alternatives for target matrix development and analysis to battle staffs noting key battlespace obstacles, including likely channels of approach, estimated enemy troop strengths, and task force hazards. Identification of most likely methods and routes for enemy Sea Lanes of Communication is critical; it is believed that, in addition to RORO (roll-on-roll-off cargo ship) assets, the PRC is employing small fishing vessels from the Spratly Islands for ground troop support. It is the goal of the battle staff to have an established RMP prior to the arrival of NESG Seven. The operating environment is expected to be aggressive (US forces to be challenged by PRC forces) but non-hostile.

Scenario Three (Stressing Scenario)

The PRC is showing little interest in removing military forces from the island of Palawan. International outcry continues to escalate in the United Nations as PRC forces continue to flow into the region. The PRC is warning that US or coalition forces massing in and around the Celebes or Philippine Sea region are to be subject to "...appropriate defensive measures." Backing words with action, interdiction of shipping by heavy PRC submarine and surface vessels is commencing in the Sulu, Celebes, and Philippine Seas. As Deprivation looms larger over the Palawan horizon, cries for international intervention are becoming more persistent. In response, four ASEAN nations -- Singapore, Japan, the Phillipines, and Indonesia -- are supplying coalition troops and equipment. The mission of CJTF SEA Tiger, the designated commander for Operation Crouching Tiger, is now being modified to re-establishing Philippine sovereignty over Palawan, NCA is directing COMPAC to commence combat operations when ready.

One PRC infantry division is entrenching itself northeast of Puerta Princessa with the maritime division, supported by components of the artillery division, fortifying the harbor region. The remaining PRC troops are dispersing throughout the mountains southwest of Puerta Princessa and the mid-island gap. The PRC's remaining Sovremenny DDGs are rendezvousing with the PRC Carrier 40 nm northwest of Palawan. J-2 assesses PRC forces in the area to be as indicated in Table 6.

Table 6 shows type and number of threats present in each scenario. In the benign scenario all threats are present at the start of the simulation. In the nominal and stressing scenarios, all ships and submarines are also generated at the start of the simulation, but waves of aircraft and ASCM launchers appear in hour and half-hour intervals, respectively. Each wave is an associated missile swarm.

Table 6. PRC Military Deployment in Scenarios One, Two, and Three

Scenario 1 Generator (Benign Scenario)		
Output Time (min)	Threat Type (ref)	Value (#)
0.5	3 x PGM	3
0.5	Diesel Sub	2

Scenario 2 Generator (Nominal Scenario)		
Output Time (min)	Threat Type (ref)	Value (#)
0.5	DDG	3
0.5	FFG	10
0.5	3 x PGM	10
0.5	MIG-31 (Fighter)	6
0.5	SU-30 (Bomber)	6
0.5	Missile	5
0.5	Diesel Sub	5
0.5	Nuc Sub	5
0.5	Mine Field	10
0.5	ASCM Launcher	5
120	MIG-31 (Fighter)	6
120	SU-30 (Bomber)	8
120	Missile	5
120	ASCM Launcher	5
240	MIG-31 (Fighter)	4
240	SU-30 (Bomber)	8
240	Missile	10
240	ASCM Launcher	10
300	MIG-31 (Fighter)	4
300	SU-30 (Bomber)	8

Scenario Generator 3 (Stressing Scenario)		
Output Time (min)	Threat Type (ref)	Value (#)
0.5	DDG	18
0.5	FFG	10
0.5	3 x PGM	7
0.5	Diesel Sub	13
0.5	Nuc Sub	5
0.5	Mini Sub	5
0.5	Mine Field	5
10	MIG-31 (Fighter)	25
10	SU-30 (Bomber)	20
10	Missile	100
10	Mine Field	5
10	ASCM Launcher	50
40	MIG-31 (Fighter)	25
40	SU-30 (Bomber)	20
40	Missile	100
40	Mine Field	5
40	ASCM Launcher	50
70	MIG-31 (Fighter)	25
70	SU-30 (Bomber)	20
70	Missile	100
70	Mine Field	5
70	ASCM Launcher	50
100	MIG-31 (Fighter)	25
100	SU-30 (Bomber)	20
100	Missile	100
100	Mine Field	5
100	ASCM Launcher	50

Stood up aboard NESG Seven, CJTF has designated all available forces to proceed to battlefield preparation phases with possible continuity towards engagement of the enemy. Specific tasking to deployed forces includes, but not limited to: Identify covertly safe water access routes to selected beach positions evaluating enemy defensive measures and force composition; identify target priorities and classify enemy MIW assets and hazards, with recommended options for neutralization of mines, to include plans for maintaining possible routes of access for follow-on expeditionary forces; develop prioritized mission area target lists for execution and include recommendations for organic battle damage assessment; confirm PRC submarine operating areas south and east of Palawan; prepare to support follow-on SEA STRIKE operations through target designation and prosecution activities related to PRC land, air, ground, surface and subsurface units.

Hostilities have begun – the PRC to attrite US forces, and NESG in self-defense.

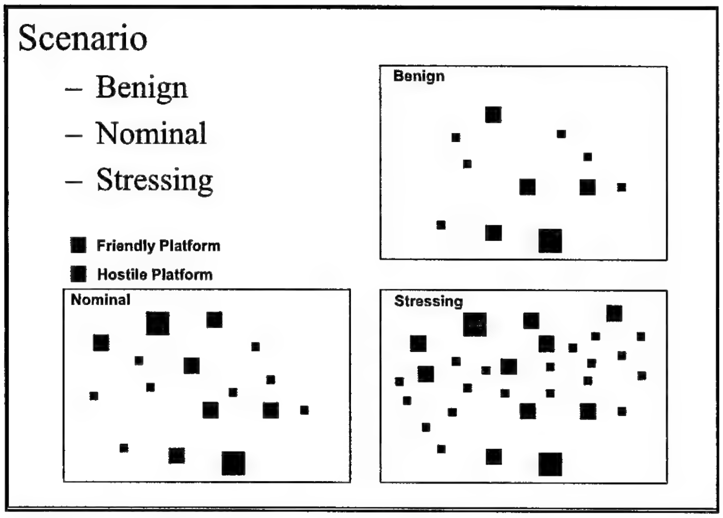


Figure 7. Scenario Hostility

SIMULATIVE STUDY

A cornerstone of the SoS development process, the simulative study, which is a Monte Carlo analysis using modeling and simulation, provides quantitative measures to assess the effectiveness of the alternative SoS architectures. Assessing the effectiveness of an alternative SoS architecture amounts to answering the following questions:

1. How much time does it require to establish the Recognized Maritime Picture (RMP)?
2. How well does it engage threats?
3. How well does it protect personnel from risk?
4. How well does it endure combat?

An architecture and a scenario constitute a configuration. The fifty-four SoS architectures and the three distinct scenarios defined above give rise to one hundred and sixty-two configurations that are subject to the Monte Carlo analysis. Fifty Monte Carlo runs are made per configuration.

Figure 8 captures the scope of the modeling and simulation and analysis in the simulative study. The input to the study includes the SoS force compositions and the scenarios. Again, each scenario is represented by the parameters that describe the physical objects in an SoS architecture and in an opposing force, and the operating environment. The physical objects are all surface, air, subsurface, and land platforms as well as major cruise missiles and mines. A physical object is characterized by its speed, turn radius, endurance, sensor range, sensor probability of detection, and weapon probability of kill. The simulated geography and the physical climate of an operating area constitute the operating environment, which is represented by terrain type, altitude, depth, atmospherics, and other ambient conditions.

The process models represent the essential SoS functions, namely, Surveillance/Threat Analysis & Evaluation, Battle Management, Communications, and Engagement. Reflecting the functional decomposition, these processes are decomposed to sub-processes. Surveillance/Threat Analysis & Evaluation breaks down to Detection, Localization, Tracking, and Kill Assessment; Battle Management to Coordination and Command; Communications to

Establish Links and Transmit; and Engagement to Engage Threats and Attrition. The development of the process models and their respective process algorithms are discussed below.

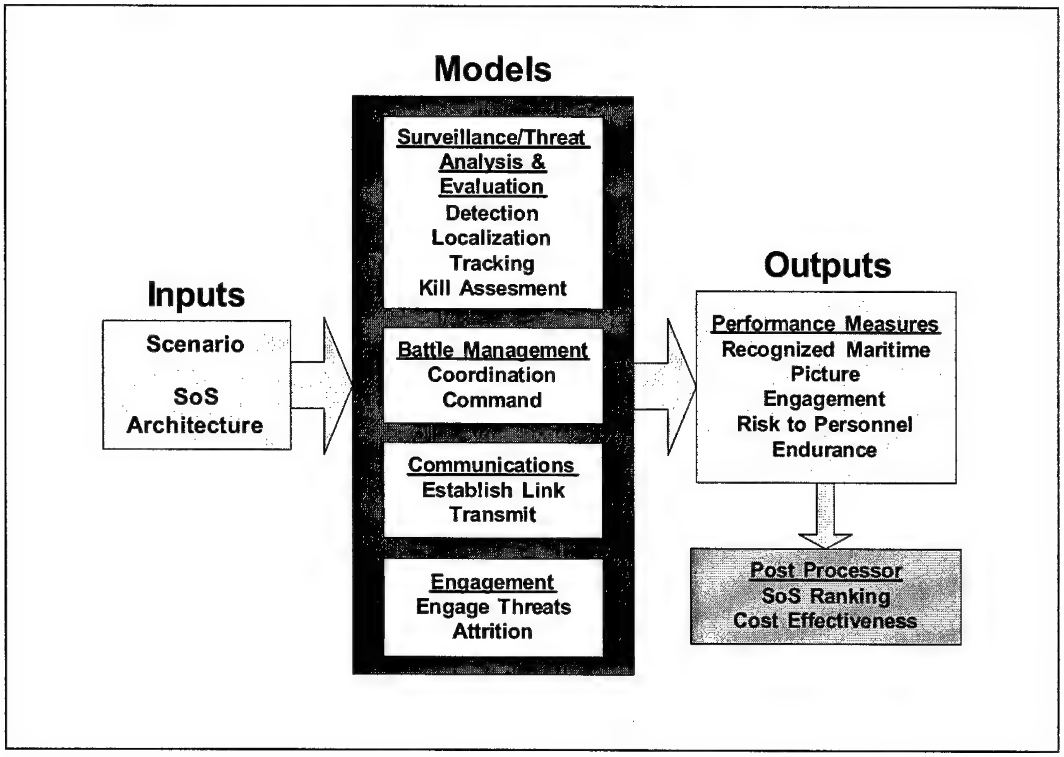


Figure 8. Simulative Study Scope

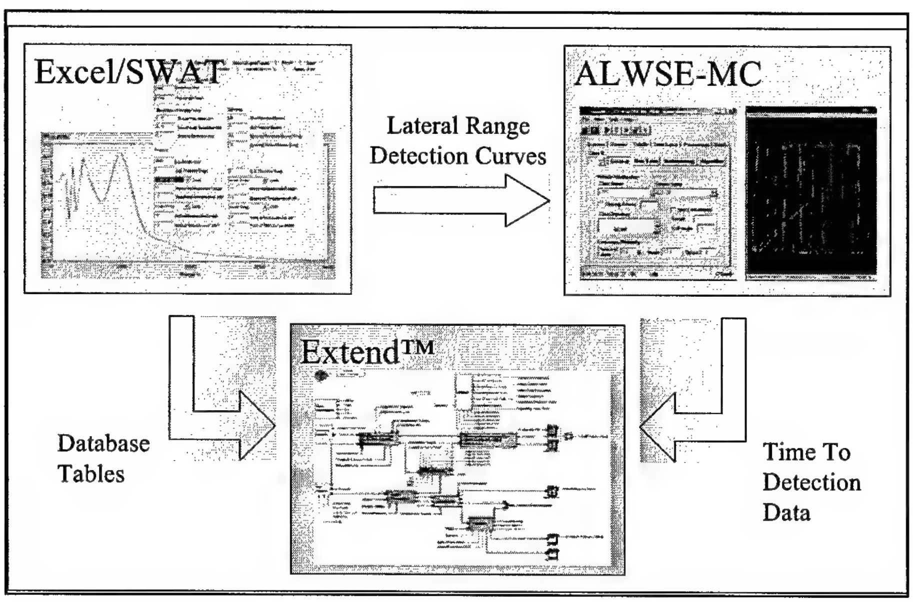


Figure 9. Simulative Study Modeling Interfaces

The simulation produces the performance measures such as the recognized maritime picture (RMP), engagement, risk to personnel, and SoS endurance. The simulative study output will be described in detail below.

Modeling and Simulation

We employ three simulation tools -- the Engineering Physics-Based Excel models combined with the Shallow Water Acoustics Toolset (SWAT), the Autonomous Littoral Warfare Systems Evaluator – Monte Carlo (ALWSE-MC), and the Force/Theater Extend™ model -- to produce the desired performance measures. Fig. 9 shows the interfaces between the modeling tools.

Engineering Physics-Based Models (Excel/SWAT)

An Excel model combined with the Shallow Water Acoustics Toolset (SWAT), the Engineering Physics-Based models create high fidelity, limited breadth models of physical phenomena for sensor/threat pairs. It creates data tables for the Force/Theater Extend™ model and sensor/threat pair probability of detection vs. range (lateral-range) curves for ALWSE-MC.

ALWSE-MC

With the probability-of-detection curves (i.e., probability vs. range) for sensor/target pairs provided by the Excel/ SWAT models, ALWSE-MC, a discrete event simulation tool that can run in batch or interactive modes, produces the time-to-detection of a target (static or mobile) by a sensor, for undersea, surface, and air missions. Each search platform is given an initial position, a search area, and a search pattern (fixed or random). Search patterns can be a diminishing square, ladder, uniform coverage, or user-defined waypoints (Gilman 2004).

Operational experience underlines the following assumptions made with running ALWYS-MC. A search area for each mission is based on a typical operating area, potentially covered by each search platform. Search speeds are either provided by operators or obtained from open sources and have no correlation to the maximum speed of the platform. Each target has a different amount of time between turns. For example, the highly maneuverable guided missile patrol boat (PGM) turns every five to ten minutes, while the guided missile destroyer (DDG) turned every thirty to forty minutes. Each search vehicle has unlimited endurance. The detection time can't thus exceed platform endurance. Search platforms and targets are confined to the search area. The targets thus can't leave the search area to avoid detection. Each platform carries only one sensor. The probability-of-detection curves used in ALWSE-MC are generated using physics based models and open sources.

Force/Theater Level Extend™ Model

The low-fidelity Force/Theater Level Model focuses on the high level SoS functions and implements the interactions between opposing forces, and examines the effects of changing the SoS force structure and architectural attributes on maritime dominance. Extend™ , Version 6, a discrete event simulation tool developed by Imagine That, Inc. (Imagine That 2002), is used to develop the Force/Theater Level Model.

The model design and process algorithms discussed below are incorporated in the Force/Theater Extend™ model, which is built in layers. The layered design keeps the upper layers of the model free from unnecessary amounts of detail and groups relevant model processes together. Figure 10 shows the top layer of the five-layer Force/Theater Extend™ model. In this top layer, each process model is represented by a hierarchical block, which contains the lower underlying layer model. The input module pulls the design variables from the run matrix for utilization throughout the model. The output module consolidates all parameters necessary to produce the performance measures.

In addition to the SoS force compositions, the threat characteristics, and the scenarios, the Force/Theater Extend™ model also needs the probabilities of kill P(K) of the various SoS weapons against the targets, the number of engagements and its uncertainty the SoS platform is allowed before a threat returns fire (which depend on the sensor and weapon capabilities of SoS and the kinematical characteristics of the threat platforms). It also needs the number of channels for SHF, UHF, VHF, and ELF (based on the available channels used in the fleet) and for the broadband 802.11 spectrum, link capacities, communication hops, connection path lengths, and platform connectivity and the communication medium. These additional data can be found in Appendix A.

The assumptions inherent in the Force/Theater Level Extend™ model follow. All SoS sensors can detect and track multiple targets simultaneously, classify and identify targets perfectly, and process their own data (so as to avoid transmitting of large amounts of raw data over the communications network). The link capacity is limited by the sending/receiving platform capabilities only at the furthest hop from the C2 node. All intermediate hops use VHF or UHF. Weapon kill probability P(K), rather than time to engage, is assumed to be the dominant factor. SoS platforms engage all enemy platforms first. A missile threat implies an enemy first strike. Input data into the Force/Theater Level Extend Model comes from the SoS force compositions and the scenarios.

Surveillance/Threat Analysis & Evaluation (S/TA&E) Algorithm

The S/TA&E model simulates searching for a target by multiple SoS sensors. Using the sensor-target pair data from ALWSE-MC, the S/TA&E algorithm determines the time to detect a target to be the smallest value of the shortest times to target detection (TTD). This time represents the total time required to search for and find the target upon its arrival in the operating area. The difference between the shortest TTD and the third shortest TTD is the time to localize the target. This represents the time required to de-conflict multiple detections of the same target and to triangulate the target position. After localization, all three sensors with the shortest TTD begin to track the target. The time to track a target by a sensor is given by $T_{Track} = 9\left(\frac{\sigma}{\sigma *}\right)^2 \Delta t$, where σ is the positional uncertainty,, σ^* the maximum allowable positional uncertainty to

engage the target, and Δt the track rate (Huynh 1984). The total time to track the target also accounts for the time of receipt of the track report by the C2 node.

Communications Algorithm

Either a track report from the S/TA&E model or an engagement order from the battle management model activates the communications model. In either case the communications algorithm determines the sending and receiving platforms. The connecting path length is the distance between the sending and receiving platform and is a function of the platform type, platform physical distribution (network diameter), and SoS C2 structure. The number of hops or message relays required to cover the connecting path is dependent on the type of platform and its link capacity, the SoS communications network architecture, and the SoS C2 structure. For each hop the type of communication link is selected based on the communication capability of a specific platform type for a given communications network architecture. A link with the highest available data rate is selected. All messages wait in a first-in-first-out (FIFO) queue for transmission with a transmission time based on the link data rate.

Battle Management Algorithm

The Battle Management algorithm sorts SoS weapons by mission area and then pairs a target with the weapon with the highest P(K) for that target. It then issues and sends engagement orders to the Communications model. Once the SoS platform associated with the paired weapon receives the engagement order, the target/weapon pair is sent to the Engagement model.

Engagement Algorithm

SoS platforms generally engage all enemy platforms first. However, in the case of a missile attack, which signifies an enemy first strike, the SoS platform will also shoot at the incoming missile. The number of shots taken by an SoS platform before the threat returns fire is dependent on the threat type. The SoS platform and the target type determine the time to engage and the SoS P(K). If the target survives, it will be either re-engaged or return fire. Except for a few special cases such as missiles or mines, a threat targets the SoS platform firing at it or the last SoS platform that fires a shot. The threat type and SoS platform type determines the time to engage process delay and the threat P(K). If the SoS platform is destroyed, the threat then targets another SoS platform. If the SoS platform survives it gets another chance to engage. Also, the Engagement algorithm calculates casualties and personnel exposed to risk, using the maximum number of personnel manning a SoS platform in Table 7 and the following rules. A destroyed SoS platform results in all personnel killed. In the stressing scenario, all destroyed SoS platforms result in casualties. In the nominal scenario, twenty-five to thirty-five percent of the SoS platforms are destroyed resulting in casualties. In the benign scenario, all SoS platforms that are hit result only in personnel exposed to risk. Also, an engagement ends with an SoS platform that could be destroyed if shot at results in all personnel exposed to risk rather than casualties.

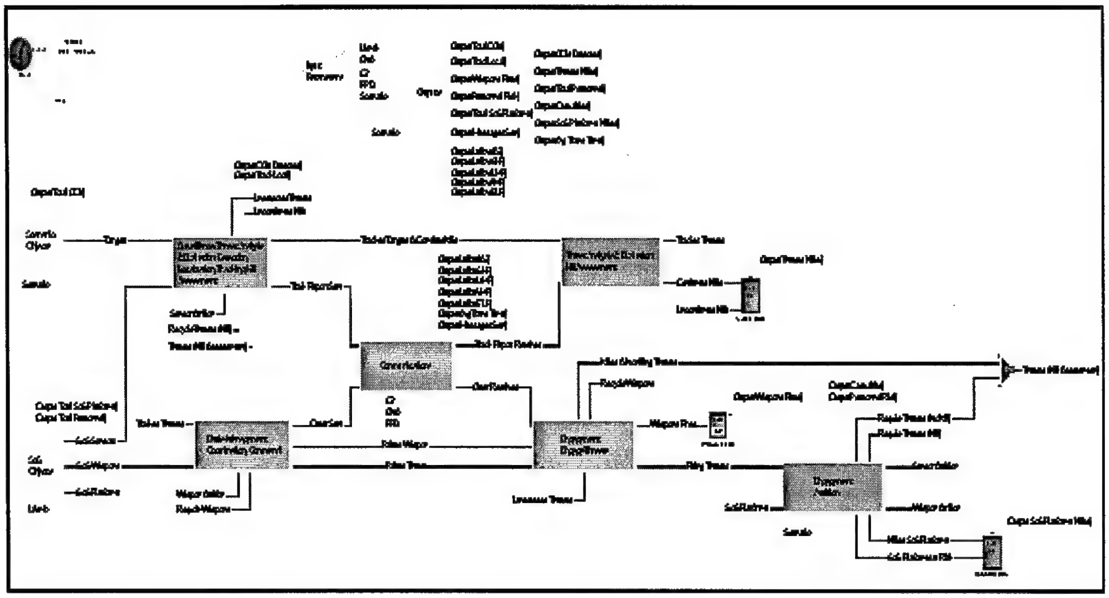


Figure 10. Top Layer of Force/Theater Extend™ Model

Experiment Design

The experiment design determines the architectures and the required number of simulation runs. Again, the design variables include the three force compositions (manned only, balanced hybrid, primarily unmanned), the three scenarios (benign, nominal, stressing), and the three CNAs (enclave, hybrid, distributed), two C2 structures (centralized, decentralized), and three PPDs (small, medium, wide). There are thus a total of one hundred and sixty-two possible configurations. Fifty Monte Carlo runs of the one hundred and sixty-two configurations result in a total of eight thousand and one hundred runs.

Output

Different types of measures of performance (MOP) generated by the Force/Theater Level Extend™ simulation are used in the calculation of measures of effectiveness (MOE), which are in turn used in assessing the simulative study objectives. Table 7 shows an example of the Extend™ output matrix. Table 8 captures the mapping of the MOP to each of the MOE. The Force/Theater Level Extend™ output consists of one hundred and sixty-two thousand data points, which are the numerical values of the measures of performance (MOP) resulting from the eight thousand and one hundred runs. The analysis of these Extend™ output data will be discussed as a part of the architecture ranking.

FORCE COMPOSITION and ARCHITECTURE RANKING

The architecture ranking process consists of an analysis of the Extend™ output data, force composition selection and ranking, and architecture selection and ranking.

Force/Theater Level Extend™ Data Analysis

Processing of the fifty data points per configuration then results in one hundred and sixty-two data points for each MOP and thereby reduces the total data points from eight hundred and sixty-two thousand data points from the Force/Theater Level Extend™ simulation to three thousand and two hundred and forty. The measures of effectiveness (MOE) are then computed from these MOP data. Since there are one hundred and sixty-two configurations, there are one hundred and sixty-two values for each MOE. The resulting data, called the processed Extend data, are input to the force composition and architecture ranking, which is discussed next.

Table 7. Extend Output Matrix

Config	Total COIs	COIs Detected	COIs Localized &	Enemy Targets Killed	Weapons Fired	Total Personnel	Personnel Exposed to Risk	Casualties	Total SoS Platforms	SoS Platforms Killed	Time to Max RMP Ratio (hrs)	Max RMP Ratio
1	5	5	5	3	5	9755	0	0	106	0	0.569	1
2	133	133	133	10	36	9755	129	455	106	3	28.905	1
3	858	858	858	47	137	9755	0	8393	106	9	30.507	1
4	5	5	5	4	5	9755	0	0	106	0	1.501	1
5	133	133	133	130	151	9755	493	646	106	2	28.533	1
6	858	858	858	14	78	9755	0	7377	106	6	32.267	1
7	5	5	5	3	4	9755	0	0	106	0	0.570	1
8	133	133	133	21	46	9755	323	728	106	2	28.599	1
9	858	858	858	279	469	9755	0	9283	106	40	30.588	1
10	5	5	5	4	4	9755	0	0	106	0	0.570	1
11	133	133	133	9	24	9755	2	129	106	1	28.090	1
12	858	858	858	226	398	9755	0	9296	106	50	38.714	1
13	5	5	5	4	4	9755	0	0	106	0	0.570	1
14	133	133	133	129	175	9755	544	1652	106	4	28.962	1
15	858	858	858	12	75	9755	0	2194	106	5	30.676	1
16	5	5	5	2	4	9755	0	0	106	0	1.157	1
17	133	133	133	109	136	9755	801	0	106	0	27.629	1
18	858	858	858	251	402	9755	0	9412	106	35	29.236	1
19	5	5	5	4	4	9755	0	0	106	0	0.570	1
20	133	133	133	19	48	9755	452	0	106	0	28.600	1

Table 8. MOP-to-MOE Mapping

Measures of Effectiveness	Measures of Performance
Surveillance	Average time to establish the RMP
Risk Exposure	Personnel Exposed to Risk
Casualties	Number of Casualties
RMP Capability	Average time to establish the RMP
	Percentage of RMP Established
Communications Capability	Average Message Transmission Time
Combat Effectiveness	Number of Enemy Platforms Killed
	Number of Shots Fired By SoS
Engagement Capability	Number of Enemy Platforms Killed
	Total Number of Enemy Platforms
	Average time to Kill Enemy Platforms
Friendly Endurance	Number of SoS platforms Killed
	Total Number of SoS platforms
Enemy Endurance	Number of Enemy Platforms Killed
	Total Number of Enemy Platforms

The force composition ranking process starts with the calculation of normalized utility scores for each MOE/configuration pair, using the processed Extend data above, and ends with the force composition ranking results. The normalized utility score for each configuration is the weighted sum of the normalized utility scores, the weights being the weights assigned to the MOE. There are thus one hundred and sixty-two scores, one for each configuration. The ensuing step in this process partitions each configuration by scenario, resulting in fifty-four architectures for each of the three scenarios, and ranks the architectures per scenario according to the utility scores. The next step determines the average utility score for each force composition within a scenario. Each average utility score of each force composition is then normalized so the total maximum utility score attained per scenario is one. Now, for each force composition, its normalized utility scores are multiplied by the respective scenario weights and the obtained results are added, thus resulting in a single utility score. Finally, these utility scores are ranked and the best force composition is one with the highest score.

Figure 11 shows the force composition ranking results. The balanced hybrid of manned and unmanned systems or Force Composition Two performs better than the other two force compositions, the primarily manned Force Composition One and the primarily unmanned Force Composition Three.

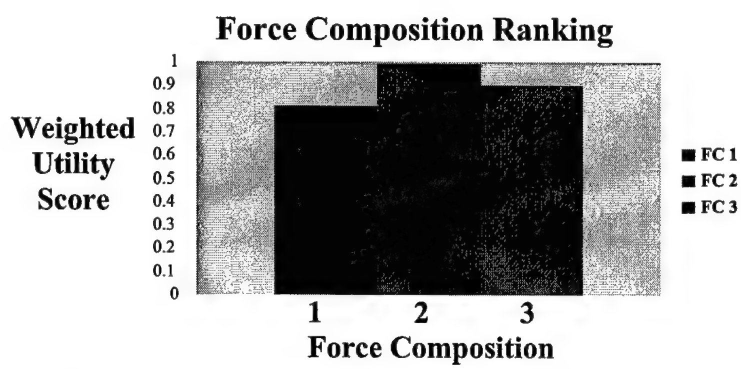


Figure 11. Force Composition Ranking Results

It is observed that a nominal unmanned to manned platform ratio of approximately 1.5 to 1 appears to result in a better performance than does a higher ratio. The ratio of approximately 4 to 1 used by Force Composition Three results in a decrease in the overall SoS performance.

Architecture Ranking

Recall that the attributes of each architecture are the force composition, communications network architecture, command and control structure, and physical platform distribution. The architecture ranking process is similar to the force composition ranking process in that both processes are identical up to the calculation of the total utility score for each configuration and their partitioning by scenario. The normalized utility score for each configuration is the weighted sum of the normalized utility scores, the weights being the weights assigned to the

MOE. There are thus one hundred and sixty-two scores, one for each configuration. Summing these one hundred and sixty-two scores over the scenarios produces fifty-four scenario-independent utility scores, one per architecture.

Now, selecting the best architecture means selecting a superior force composition in conjunction with the most effective communications architecture network, command and control structure and physical platform distribution. Figure 12 shows the three top performance architectures – (1,3,2,1), (2,3,2,2), and (3,3,2,3).

	Communication			Command and Control		Platform Physical Distribution		
Architecture	Enclave	Hybrid	Distributed	Centrallized	Decentralized	Small	Medium	Large
Architecture 1			X		X	X		
Architecture 2			X		X		X	
Architecture 3			X		X			X

Figure 12. Architecture Performance Results

From the study results, the enclave, hybrid and distributed communications network architectures show statistical difference when applied to the various MOE. The distributed communications network architecture is the preferred choice for all three of the top performing architectures. The ability for almost all SoS platforms to communicate with each other reduces the average message delay between reporting units and receiving units. The distributed communication network architecture (CNA) has an average message delay that is one tenth that of the hybrid CNA and one hundredth that of the enclave CNA. The distributed CNA also results in a minimum effect on message throughput when communication nodes are lost.

The command and control (C2) structures are also statistically significant in deciding the best performance of the selected architectures. The top architectures all employ the decentralized C2 structure, which allows for a faster dissemination of command messages, due to the proximity of C2 nodes to sensor or reporting platforms. The average command message delay of a decentralized structure is one tenth that of the centralized structure. The decentralized C2 also results in faster reaction times than those architectures with a centralized C2 structure, also a result of the command and control nodes being in a closer proximity to the forward deployed platforms. Furthermore, more C2 nodes in an SoS results in a decrease in network demand and single node workload. The final benefit of a decentralized C2 structure is the elimination of a single point of failure. If a C2 node is lost in decentralized system, its function can be picked up by another C2 node. In a centralized system the lost of a single node would be catastrophic. Decentralized command and control thus increases system survivability and reliability.

Sensitivity Analysis

We also perform an independent statistical analysis on the raw Force/Theater Level Extend™ simulation data (MOP) to identify the best performance SoS architecture (i.e., one that yields the best MOE), then compare the selected architecture above to the best performance SoS

architecture, and thereby validate the architecture ranking and selection with respect to architecture performance, attribute effects, and cost effectiveness. We consider the following MOE: RMP capability, engagement capability, risk to personnel, and battle endurance.

Architecture Performance

The RMP capability is reflected by the time to establish the RMP; the engagement capability by the percentage of enemy platforms destroyed; risk to personnel by the total lives put at risk and casualties; and battle endurance by the percentage of SoS surviving platforms. The number of personnel varies with force composition.

The ranking analysis above finds that Configuration 105 (corresponding to Force Composition Two), Configuration 162 (corresponding to Force Composition Three) and Configuration 48 (corresponding to Force Composition One) perform the best in Scenario Three across all MOE. This statistical analysis finds that Configuration 108 (which corresponds to Force Composition Two) provides the best RMP capability in Scenario Three.

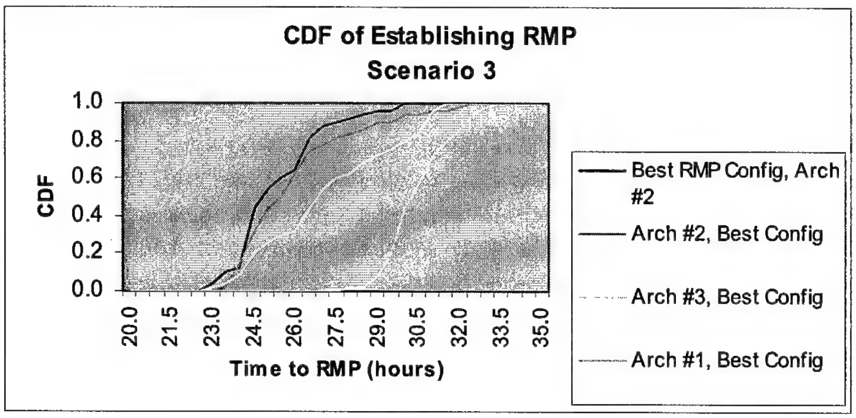
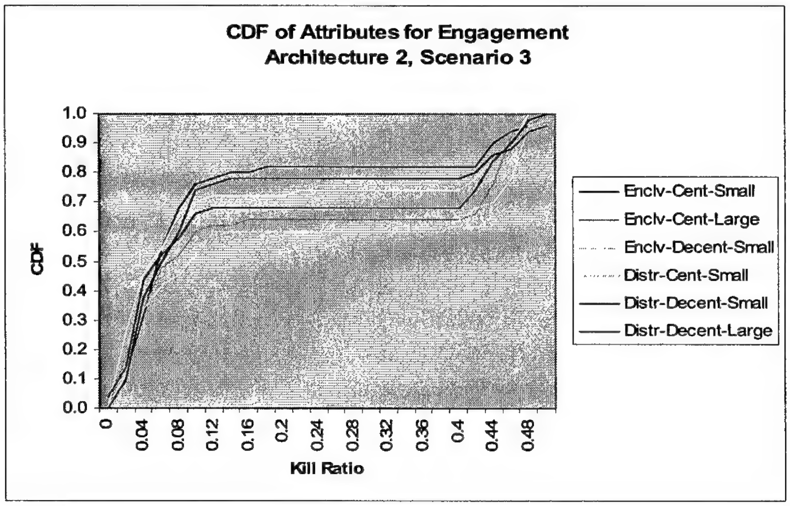


Figure 13. CDF for Establishing the Recognized Maritime Picture

As shown by Figure 13, which displays the cumulative density function (CDF) for the time to establish the RMP for the respective configurations, Force Composition Two is comparable to the best RMP performing force composition, in that the probability that the difference in RMP capability between the two configurations is only one hour falls between 80% and 90%. The primarily unmanned and manned compositions exhibit considerably poor performance -- a four and five hour difference, respectively, from the best performing force composition (configuration). While not shown here, the CDF for the time to establish the RMP remains consistent for the other scenarios.

Except for engagement capability, the selected force composition is comparable to the best performing force composition in the most stressing scenario for all MOE. While the manned only force composition is comparable to the best performance force composition in engagement capability, the mixed hybrid architecture has considerably poorer performance (less than 60% probability), but does reach a higher kill ratio (above 80). In fact, the less hostile scenarios favor

the primarily manned composition (SEA5 2004). The results for the other MOE can be found in (SEA5 2004).



Attribute Effects

Figure 14. Effects of Architecture Attributes on Engagement

We now assess the effects of the architecture attributes (CNA, C2, and PPD) on the performance of the SoS architectures. For Force Composition Two and Scenario Three, the CDF of the kill ratio (representing engagement capability) in Figure 14 indicates that the architecture attributes of distributed CNA, centralized C2, and small PPD outperform the other attribute combinations. These CDF provide insight into which attributes are aiding in SoS success and provide insight into which attributes and architectures should be tested for statistical differences.

For combat endurance and communications performance, however, no conclusion can be made as to which attributes contribute to architecture success. Finally, while no single attribute could be established as the dominant factor in performance for combat endurance, the distributed CNA and decentralized C2 do contribute to communications performance (SEA5 2004).

Data Quality Assessment

We also assess the quality of the simulation data using box plots for the MOE. As shown by the box plot on the left in Figure 15, the tight distribution of the time-to-establish-RMP data for each force composition indicates good quality in the data. The box plot on the right indicates a statistical difference between all three force compositions and the mix hybrid architecture with the lowest times to establish the RMP. For Force Composition Two, Figure 16 indicates small spread in the data, again ascertaining the good quality of the data. While not shown here, the same behavior is exhibited with the other force compositions, with respect to the time to establish the RMP (SEA5 2004).

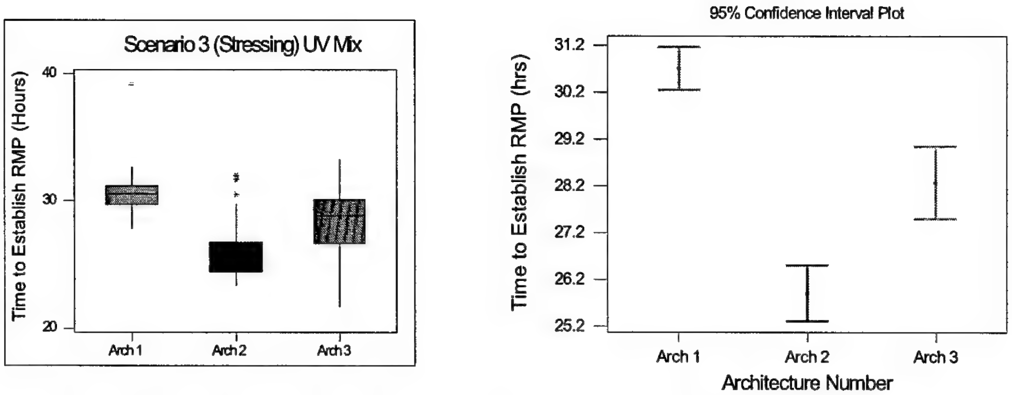


Figure 15. Recognized Maritime Picture with a 95 Percent Confidence Interval

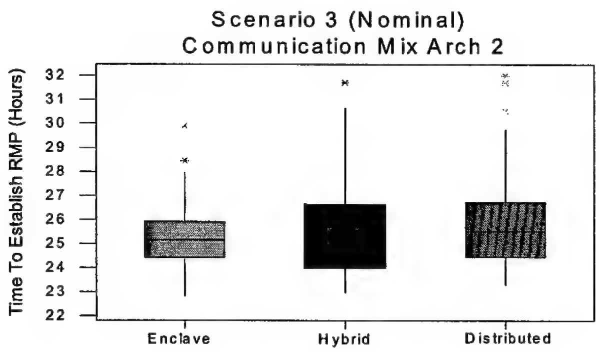


Figure 16. Time to Establish RMP Dispersion

RECOMMENDED SoS ARCHITECTURE

Based on a cost model developed during this work (SEA5 2004) and the cost data obtained from open sources and the Defense Automated Cost Information System (DACIMS) provided by the Pentagon, the total ownership cost (TOC) of each system of systems is the sum of the costs of operation and support (O&S) and purchase of the platforms in the SoS. Table 9 shows the TOC for the three force compositions. The underlying costing method uses a basis of a ten-year lifecycle to standardize costs across the different platforms and provides a point estimate only; no variance of the data is taken into account. The cost estimate, however, will adjust itself if the lifecycle of the platforms is adjusted. Finally, the unmanned platform costs are estimated using an analogy technique (SEA5 2004).

Figure 17 shows that the mix hybrid force composition is both cost effective and cost efficient. The manned only force composition is shown to be cost effective and not cost efficient, while the primarily unmanned force composition is dominated by the other two options

(neither cost effective nor efficient). In fact, for Force Composition Three, cost increases while performance degrades.

The independent statistical analysis shows that the selected balanced hybrid force composition (FC 2) is in excellent agreement with the best performance force composition in the stressing scenario. The mix hybrid force composition clearly outperforms the other alternatives with respect to RMP establishment, risk to personnel, and communications capability. The distributed communications network architecture and decentralized command and control contribute to superior SoS performance.

The recommended SoS architecture for the 200 nm by 200 nm littoral operating area is thus (2,3,2,2); that is, a balanced hybrid system of manned and unmanned systems that are physically distributed in a 100-nm diameter area and that uses a distributed communications network and a decentralized command and control structure.

		Cost in FY04$B	
Architecture	**Purchase Cost**	**O&S**	**TOC**
Manned Only (Force Comp 1)	0	1.53	23
Balanced Hybrid (Force Comp 2)	4.7	1.34	24.3
Primarily Unmanned (Force Comp 3)	10.4	1.13	25.8

Table 9. Total Ownership Cost Estimates for The Three Force Compositions

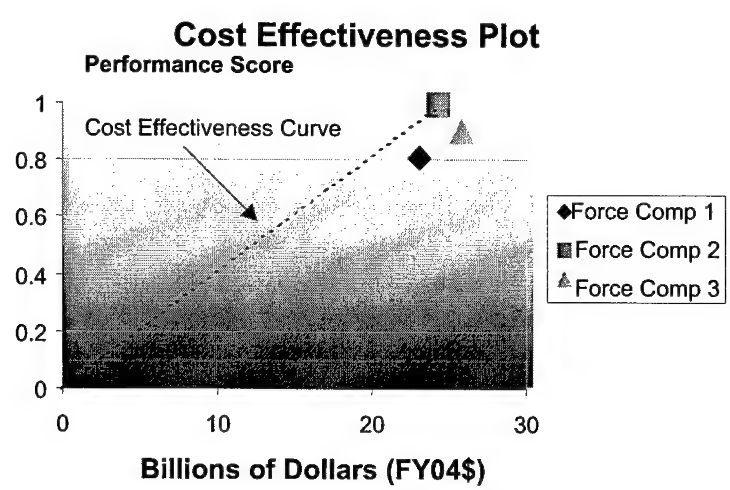


Figure 17. SoS Force Composition Cost Effectiveness

CONCLUSION

In this work we define the alternatives of a conceptual system of systems (SoS) and to recommend a cost-effective SoS architecture that would enable SEA BASING and SEA STRIKE for maritime dominance in the littorals in the 2020 timeframe. The SoS would consist of sea-based, land-based, an airborne sensor and weapon systems that are (i) both manned and unmanned, (ii) in existence, in development, and future concepts, and (iii) networked via communications links and space systems to achieve success of the following littoral missions in an operating area of 200 nm inland by 200 nm offshore in the South China Sea, with the minimum risk to personnel: (1) Establishment of the Recognized Maritime Picture (RMP); (2) Identification and, if necessary, reduction of hostile threats to within capability of the sea base; and (3) enabling projection of offensive capabilities from the sea.

Three SoS force compositions are considered: only manned platforms, primarily unmanned platforms, and a balanced manned and unmanned platforms. According to the findings in this work, enabling SEA BASING and SEA STRIKE for achieving maritime dominance in the littorals in the 2020 timeframe in a cost effective manner requires a balanced hybrid system of manned and unmanned systems that uses a distributed communications network and a decentralized command and control structure. The distributed communications network provides for faster dissemination of information and shorter message delay while decentralized command and control reduces single-node workload and prevents C2 collapse in the event of C2 node loss. Furthermore, the longest distance between two platforms in a deployed SoS is called the diameter of the distribution of the SoS platforms. For this 200- nm by 200-nm littoral operating area, the 100-nm diameter hybrid SoS is recommended. The 50-nm and 150-nm diameters have not been found to significantly improve SoS performance. Finally, unmanned platforms complement but cannot replace manned systems.

The findings of this study thus suggest that a system of only unmanned platforms does not provide a silver-bullet solution to the problem of maritime dominance in the littorals in 2020 time frame; unmanned platforms thus complement but cannot replace manned systems. Manned platforms will still be required to implement command and control and make crucial operational decisions. As unmanned vehicles in the 2020 timeframe by themselves will not have the ability to adapt to dynamic threat environments, manned platforms will remain an essential command and control element in military force structures. Furthermore, limited in endurance and thereby requiring manned system support, unmanned vehicles cannot completely keep personnel out of harm's way, yet they greatly reduce the level of risk to which personnel are exposed.

While the findings of this integrated project provide some insight into the SoS solution to the problem of maritime dominance in the littorals in the 2020 timeframe, further research is needed to provide additional insight and to assess the robustness of the findings. We recommend the following future research activities:

- Develop an efficient approach to consider a wide range of force compositions (unmanned/manned platform mixes) and determine an optimal force composition.
- Develop and implement composite tracking algorithms and multi-sensor fusion algorithms and assess the performance of an SoS in multiple-target tracking and identification and thereby its effects on engagement.

- Implement standard and military network access protocols in the EXTEND™ simulation and assess the throughput and delay of data and command messages.
- Implement many-on-many engagement algorithms in an appropriate simulation to determine an optimal force size against postulated threats and to assess combat effectiveness of an SoS.
- Include space-based sensors and communications satellites in an SoS and assess its contribution to the SoS effectiveness.
- Incorporate concepts of operations (CONOPS) in the Extend™ simulation or in any other appropriate simulation to determine their impact on the performance of an SoS.
- Take into account the reliability of unmanned vehicles in order to determine an optimal number of unmanned vehicles in a hybrid SoS and to establish its operational logistics.
- Incorporate realistic models of infrared sensors, acoustic sensors, and radar, in particular, foliage penetration radar, and related processing algorithms in an SoS simulation in order to assess their collective impact on detection and tracking in littoral operating environments.
- Incorporate realistic models of littoral environments (e.g., clutter models) in an SoS simulation in order to assess performance accuracy of the sensors above and thereby the effectiveness of an SoS.
- Implement decision-making algorithms at command and control nodes in the EXTEND™ simulation in order to assess the SoS reaction time and battle management effectiveness.
- Conduct the study carried out in this project with entirely different littoral environments (such as in the Middle East) in order to determine an optimal SoS composition for various environments.
- Conduct a cost analysis in order to provide estimates on a total ownership cost and its variability for each SoS.
- Incorporate UV reliability measures into appropriate simulations in order to optimize the number of UVs necessary to meet operational requirements and to evaluate SoS performance.
- Perform the study carried out in this project using pertinent classified data and information in order to provide realistic assessment of the performance of the SoS and thereby to aid decision makers in developing and implementing an operational SoS.

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Peterson, ENS Edward S. Poitevent, ENS Marlin R. Smith, ENS Emanuel M. Tsikalas, ENS Cavan S. Tubbs, all of USNR.

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APPENDIX A. ADDITIONAL FORCE/THEATER EXTEND™ INPUT

The following tables contain the additional input to the Force/Theater Extend™ model.

Table 10. SoS Architecture Times to Engage

SoS Platform TTE (min)					
SoSPlatformType	Surface Target	Air Target	Subsurf Target	Mine Target	Land Target
CVN		1.9			
CG	4.3	1.9	9.1		5.7
CGX	4.3	1.9	9.1		5.7
DDG	4.3	1.9	9.1		5.7
DDX	4.3	1.9	9.1		5.7
LCS	4.3	1.9	9.1	75.0	
FFG	4.3	1.9	9.1		
MHC				225.0	
MCM				225.0	
LHA		1.9			
SSN	9.1		9.1		5.7
P-3	4.3		9.1		
MMA	4.3		9.1		
SH-60	0.3		9.1		
MH-53				75.0	
F/A-18	4.3	0.7			5.0
F-14	4.3	0.7			5.0
E/A-6B					5.0
B-2					5.0
B-52					5.0
F-117					5.0
JSF	4.3	0.7			5.0
F-16	4.3	0.7			5.0
F-22	4.3	0.7			5.0
S-3	4.3		9.1		
SSGN	9.1		9.1		5.7
USV-1					
USV-2	0.3			75.0	
UAV-4	4.3				5.0
UAV-5	0.3				0.3
ASW UUV	9.1		9.1		

Table 11. SoS Architecture P(K)

Surface P(K)			
SoSWeaponType	**DDG**	**FFG**	**PGM**
Harpoon	0.3	0.3	0.6
Torpedo	0.6	0.6	0.8
JSOW	0.3	0.3	0.8
Penguin	0.3	0.3	0.6
LCS Gun	0.3	0.4	0.5
Hellfire	0.05	0.1	0.3

Mine P(K)	
SoSWeaponType	**Mine**
EOD Team	0.95
MH-53 Sled	0.6
USV Sled	0.6

Air P(K)			
SoSWeaponType	**Fighter**	**Bomber**	**Missile**
SM-2	0.85	0.85	0.7
RAM	0.85	0.85	0.7
Sea Sparrow	0.85	0.85	0.7
AIM-9X	0.7	0.7	0

Land P(K)	
SoSWeaponType	**ASCM Launcher**
Tomahawk	0.85
JSOW	0.7
Hellfire	0.6
JDAM	0.7
HARM	0.7

Subsurface P(K)			
SoSWeaponType	**Diesel Sub**	**Nuc Sub**	**Mini Sub**
Torpedo	0.6	0.7	0.8

Table 12. SoS ArchitectureEngagements

Number of Engagements		
Threat Type	Misses (#)	
DDG	2	(+/-1)
FFG	2	(+/-1)
PGM	2	(+/-1)
Fighter	3	(+/-1)
Bomber	3	(+/-1)
Missile	(1 or 2)	
Diesel Sub	(2 or 3)	
Nuc Sub	(2 or 3)	
Mini Sub	(2 or 3)	
Mine	1	
Missile Launcher	2	

Table 13. Sensor Time To Track Data

Surface Sensor		
SoSSensorType	Sigma (m)	Delta T (sec)
EF-Band	7.40048	1
K-Band	0.014781	1
X-Band	0.014781	1
AN/SPS 67	60.3472	0.083
AN/SPS 55	38.751	0.083
Air Borne B-Band	0.44751	30
EF + IR	7.40048	1
AN/SPS 55D + 67	38.751	0.083
AN/SPS 55D + 67 + IR	38.751	0.083
B-BandD	1.65704	30
IR	3.5	1

Mine Sensor		
SoSSensorType	Sigma (m)	Delta T (sec)
Surf	762.5	0.5
Helo	653.6	0.5
UUV	183	0.5

Land Sensor		
SoSSensorType	Sigma (m)	Delta T (sec)
FolPen	10	0.1

Air Sensor		
SoSSensorType	Sigma (m)	Delta T (sec)
EF-Band	11.2778	1
K-Band	0.035496	1
X-Band	0.035496	1
AN/SPS 49	198.794	0.083
B-Band	5995.91	30
B-BandD	18960.7	30

Subsurface Sensor		
SoSSensorType	Sigma (m)	Delta T (sec)
Surf	190.625	0.5
Sub	762.5	0.5
P3	500	0.5
UUV	381.25	0.5

Threats	
Threat Type	Sigma* (nm)
DDG	0.5
FFG	0.5
PGM	0.5
Fighter	1
Bomber	1
Missile	1
Diesel Sub	0.8
Nuc Sub	0.8
Mini Sub	0.8
Mine	0.02
Missile Launcher	1

Table 14. Communication Link and Message Parameters

Comms Link Generator		
Comm Link	Channels (#)	Data Rate (Kbps)
802.11	27	2000
SHF	80	105
UHF	79	0.81
VHF	36	0.44
ELF	2	0.6

Messages	
Type	Size (bits)
Track Report	704
Kill Assessment	256
Engagement Order	192

Table 15. Communication Hops

Enclave Hops (#)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	1	1
CGX	1	1
DDG	1	1
DDX	1	1
LCS	2	1
FFG	2	1
MHC	2	1
MCM	2	1
LHA	1	1
SSN	2	2
E-2C	1	1
E-8	1	1
E-3	1	1
P-3	1	1
MMA	1	1
SH-60	2	1
MH-53	3	2
F/A-18	1	1
F-14	1	1
E/A-6B	1	1
B-2	2	1
B-52	2	1
F-117	2	1
JSF	2	1
F-16	2	1
F-22	2	1
S-3	1	1
SSGN	2	1
USV-1	3	2
USV-2	3	2
UAV-1	2	1
UAV-2	4	2
UAV-3	4	2
UAV-4	4	2
UAV-5	4	2
MIW UUV	4	2
ASW UUV	4	2

Hybrid Hops (#)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	1	1
CGX	1	1
DDG	1	1
DDX	1	1
LCS	2	1
FFG	2	1
MHC	2	1
MCM	2	1
LHA	1	1
SSN	2	2
E-2C	1	1
E-8	1	1
E-3	1	1
P-3	1	1
MMA	1	1
SH-60	2	1
MH-53	3	2
F/A-18	1	1
F-14	1	1
E/A-6B	1	1
B-2	2	1
B-52	2	1
F-117	2	1
JSF	2	1
F-16	2	1
F-22	2	1
S-3	1	1
SSGN	2	1
USV-1	2	1
USV-2	2	1
UAV-1	2	1
UAV-2	3	2
UAV-3	3	2
UAV-4	3	2
UAV-5	3	2
MIW UUV	3	2
ASW UUV	3	2

Distributed Hops (#)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	1	1
CGX	1	1
DDG	1	1
DDX	1	1
LCS	1	1
FFG	1	1
MHC	1	1
MCM	1	1
LHA	1	1
SSN	1	1
E-2C	1	1
E-8	1	1
E-3	1	1
P-3	1	1
MMA	1	1
SH-60	1	1
MH-53	1	1
F/A-18	1	1
F-14	1	1
E/A-6B	1	1
B-2	2	1
B-52	2	1
F-117	2	1
JSF	2	1
F-16	2	1
F-22	2	1
S-3	1	1
SSGN	1	1
USV-1	2	1
USV-2	2	1
UAV-1	2	1
UAV-2	2	1
UAV-3	2	1
UAV-4	2	1
UAV-5	2	1
MIW UUV	2	1
ASW UUV	2	1

Table 16. Communication Capability Matrix

	Communication Capability		
SoSPlatformType	Enclave	Hybrid	Distributed
CVN	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
CG	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
CGX	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11	UHF+VHF+SHF+ELF+802.11
DDG	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11	UHF+VHF+SHF+ELF+802.11
DDX	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11	UHF+VHF+SHF+ELF+802.11
LCS	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11	UHF+VHF+SHF+ELF+802.11
FFG	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
MHC	ELF+UHF	ELF+UHF	UHF+VHF+SHF+ELF+802.11
MCM	ELF+UHF	ELF+UHF	UHF+VHF+SHF+ELF+802.11
LHA	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
SSN	ELF+UHF	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11
E-2C	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
E-8	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
E-3	UHF+VHF+SHF	UHF+VHF+SHF+802.11	UHF+VHF+SHF+ELF+802.11
P-3	UHF+VHF	UHF+VHF+SHF	UHF+VHF+SHF+802.11
MMA	UHF+VHF	UHF+VHF+SHF	UHF+VHF+SHF+802.11
SH-60	UHF+SHF	UHF+SHF	UHF+SHF+802.11
MH-53	UHF+SHF	UHF+SHF	UHF+SHF+802.11
F/A-18	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
F-14	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
E/A-6B	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
B-2	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
B-52	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
F-117	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
JSF	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
F-16	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
F-22	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
S-3	UHF+VHF	UHF+VHF	UHF+VHF+SHF+802.11
SSGN	ELF+UHF	UHF+VHF+SHF+ELF	UHF+VHF+SHF+ELF+802.11
USV-1	VHF	VHF+802.11	VHF+802.11
USV-2	VHF	VHF+802.11	VHF+802.11
UAV-1	UHF+VHF	UHF+802.11	UHF+802.11
UAV-2	UHF	UHF+802.11	UHF+802.11
UAV-3	UHF	UHF	802.11
UAV-4	UHF	UHF	802.11
UAV-5	UHF	UHF	802.11
MIW UUV	ELF+UHF	ELF+UHF	ELF+UHF
ASW UUV	ELF+UHF	ELF+UHF	ELF+UHF

Table 17. Communication Link Lengths

Small PPD CommRange (nm)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	5	2.5
CGX	5	2.5
DDG	10	5
DDX	10	5
LCS	10	5
FFG	10	5
MHC	30	15
MCM	30	15
LHA	5	2.5
SSN	30	15
E-2C	10	5
E-8	10	5
E-3	10	5
P-3	10	5
MMA	10	5
SH-60	5	2.5
MH-53	5	2.5
F/A-18	50	25
F-14	50	25
E/A-6B	50	25
B-2	100	50
B-52	100	50
F-117	100	50
JSF	50	25
F-16	50	25
F-22	50	25
S-3	50	25
SSGN	30	15
USV-1	5	2.5
USV-2	5	2.5
UAV-1	2	1
UAV-2	20	10
UAV-3	50	25
UAV-4	70	35
UAV-5	100	50
MIW UUV	10	5
ASW UUV	100	50

Medium PPD CommRange (nm)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	7.5	3.75
CGX	7.5	3.75
DDG	15	7.5
DDX	15	7.5
LCS	15	7.5
FFG	15	7.5
MHC	45	22.5
MCM	45	22.5
LHA	7.5	3.75
SSN	45	22.5
E-2C	15	7.5
E-8	15	7.5
E-3	15	7.5
P-3	15	7.5
MMA	15	7.5
SH-60	7.5	3.75
MH-53	7.5	3.75
F/A-18	75	37.5
F-14	75	37.5
E/A-6B	75	37.5
B-2	150	75
B-52	150	75
F-117	150	75
JSF	75	37.5
F-16	75	37.5
F-22	75	37.5
S-3	75	37.5
SSGN	45	22.5
USV-1	7.5	3.75
USV-2	7.5	3.75
UAV-1	3	1.5
UAV-2	30	15
UAV-3	75	37.5
UAV-4	105	52.5
UAV-5	150	75
MIW UUV	15	7.5
ASW UUV	150	75

Large PPD CommRange (nm)		
SoSPlatform	Centralized	Decentralized
CVN	0	0
CG	10	5
CGX	10	5
DDG	20	10
DDX	20	10
LCS	20	10
FFG	20	10
MHC	60	30
MCM	60	30
LHA	10	5
SSN	60	30
E-2C	20	10
E-8	20	10
E-3	20	10
P-3	20	10
MMA	20	10
SH-60	10	5
MH-53	10	5
F/A-18	100	50
F-14	100	50
E/A-6B	100	50
B-2	200	100
B-52	200	100
F-117	200	100
JSF	100	50
F-16	100	50
F-22	100	50
S-3	100	50
SSGN	60	30
USV-1	10	5
USV-2	10	5
UAV-1	4	2
UAV-2	40	20
UAV-3	100	50
UAV-4	140	70
UAV-5	200	100
MIW UUV	20	10
ASW UUV	200	100